24

NASA TECHNICAL TRANSLATION

NASA TT F-13,884

THE WAVELENGTH DEPENDENCE OF ATMOSPHERIC EXTINCTION

J. Wempe

13884

Translation of "Die Wellenlaengenabhaengigkeit der atmosphaerischen Extinktion", Astronomische Nachrichten, Vol. 275, No. 1, 1947, pp. 1-22

N72-14843 (NASA-TT-F-13884) THE WAVELENGTH DEPENDENCE OF ATMOSPHERIC EXTINCTION J. Wempe (Techtran Corp.) Oct. 1971 43 p CSCL 03B

Unclas
11730
G3/30

FACI (NASA CR OR TMX OR AD NUMBER) (CATEGORY)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 OCTOBER 1971

THE WAVELENGTH DEPENDENCE OF ATMOSPHERIC EXTINCTION[1]

J. Wempe

ABSTRACT. The spectral gradients of monochromatic extinction coefficients under various atmospheric conditions show a strong correlation with visual extinction. Fog extinction obtained by subtracting from the total extinction the components due to molecular scattering of the permanent gases and the selective absorption by ozone may be expressed by β/λ^{α}, with the exponent $\alpha = 1.5$ at Jena and 0.6 to 1.5 at other locations, independent of haze, and β, a measure of the total mass of haze in the atmosphere.

INTRODUCTION

The results of 18 determinations of spectra-photometric extinction under the most varying atmospheric conditions are reported as empirical bases for a systematic investigation of the wavelength dependence of atmospheric extinction. The spectral gradients of monochromatic extinction coefficients show a strong correlation with the magnitude of the visual extinction; the results from other observations fit in with this statistical interrelation. /1*

The possibility of separating the extinction components of varying origin for the purpose of more accurately investigating the temporary and local differences of extinction is discussed. The component obtained by scattering on the molecules of the atmospheric permanent gases may be computed by the Rayleigh theory. The selective absorption of ozone in the Chappuis band may be determined with sufficient accuracy from the layer density and the absorption coefficient. The amount remaining after subtracting these two components of the observed total extinction is the subject of further investigation as fog extinction.

The fog extinction obtained from the observations at Jena may be represented in the visible spectra range by the interpolated statement β/λ^{α} with an ex-

---

[1] (No. 21--Contribution from the Astrophysical Observatory, Potsdam), Accepted as an inaugural dissertation by the Mathematical-Natural Science Faculty of the University of Jena.

*Numbers in the margin indicate pagination in the foreign text.

ponent $\alpha = 1.5$, which is independent of the turbidity. An equivalent markup of observational material available from other locations yields values for the wavelength exponents of the fog extinction which is always between 0.6 and 1.5 and which can be ascribed to local differences in the composition of the fog.

The parameter representation of the fog extinction provides the possibility of computing from the extinction value of any one observed wavelength (for example, from the visual extinction) the monochromatic extinction coefficients in the spectral range of $400\ \mathrm{m}\mu < \lambda < 700\ \mathrm{m}\mu$ as the approximate sum of the various components.

1. Preliminary Remarks

In astrophysics, atmospheric extinction and its wavelength dependence are usually considered to be an unavoidable reduction element during spectrophotometric and colorimetric work, and its investigation is restricted to the degree required for it. The observations for the determination of extinction are therefore often designed (especially for work in the derivation of color temperatures) to yield only the spectral gradients directly required for the consideration of the extinction and not the monochromatic extinction value itself. Such a limitation, however, impedes the discussion of the local and temporary changes which empirically underlie the extinction, because it makes it impossible to separate in the total extinction the components of different origins contained in it (scattering and absorption by the permanent gases, effect of water vapor and fog). For the magnitude and wavelength dependence of individual extinction components partly theoretical statements and partly empirical data are available. By using this knowledge, it is possible to separate the variable component and investigate possible mathematical interrelations separately.

It seemed desirable to base this investigation on new study material of the most accurate individual extinction determinations possible. For this purpose, a series of spectrophotometric extinction determinations at very different atmospheric conditions was undertaken at Jena. They were determined by both the customary procedure of forming gradients and by a separate investigation of the various extinction components. To clarify the question of whether the mathematical relationship found at Jena for the fog extinction could be carried over to studies at other locations, the spectrophotometric extinction determinations under study which are usable for such an investigation, are subjected to a uniform discussion.

2. The Extinction Determinations at Jena

The determination of the monochromatic extinction magnitude is obtained by spectrophotometric comparison of a star near the zenith (zenith distance $Z_1 <$ $< 20°$) with a second star at greater zenith distance Z_2, which was always chosen between 50° and 60°. The use of the star pair is more advantageous than the temporary pursuit of a simple object over different zenith distances, something which is unavoidable in daylight observations of the sun. The result is practically independent of temporary variations of atmospheric optical visibility and /2 the sensitivity of the measuring arrangement. The procedure simply assumes the uniformity of the atmospheric condition at different zenith distances, i.e., a pattern of the turbidity in homogeneous horizontal layers. When superterrestrial monochromatic brightness of the two stars is expressed in classes of magnitude with $m_1^{\circ}(\lambda)$ and $m_2^{\circ}(\lambda)$ then the observed brightnesses $m_1^{z}1(\lambda)$ and $m_2^{z}2(\lambda)$ are

$$m_1^{z_1}(\lambda) = m_1^0 + k_\lambda \cdot F(z_1)$$
$$m_2^{z_2}(\lambda) = m_2^0 + k_\lambda \cdot F(z_2),$$

when

$$k_\lambda = -2{,}5 \log p_\lambda$$

of the monochromatic extinction coefficient and p_λ is the transmission coefficient set as the uniformity of the path length F(z) for the vertical column of air. For zenith distances less than 60° to which photometric observations are generally restricted, the path length F(z) can simply be set equal to sec z. The extinction coefficient k is thus equal to the zenith extinction in class magnitude or is equal to the zenith reduction for a star at zenith distance 60°. The photometric observation of a star pair in the zenith distances z_1 or z_2, respectively, yields the brightness difference $m_1{}^{z}1 - m_2{}^{z}2 = \Delta m_z$. It is also known as the difference of the superterrestrial or the zenith related brightness $m^{\circ}{}_1 - m_2^{\circ} = \Delta m_\circ$, so that the extinction coefficient becomes

$$k_\lambda = \frac{\Delta m_z - \Delta m_0}{\Delta \sec z}.$$

The measurement of the magnitude Δm_z took place photographic-photometrically on exposures with a mirror prism camera, consisting of a parabolic mirror of 200 cm focal length and 30 cm aperture, as well as two prisms of UV-glass of 8° and 12° refracting angle and 25 cm free aperture, which together yielded a dispersion of 39 Å/mm at 4,000 Å, 92 Å/mm at 5,000 Å, and 165 Å/mm at 6,000 Å. A coarse diffraction lattice attachable in the parallel path of rays before the prism, and produced in the observatory workshop, served to produce the photometric scale. Pure nickel wires of 1 mm thickness were led over mandrels of 2 mm pitch, so that the width of the clearance was very nearly equal to the width of the wire. Inasmuch as the lattice came out very uniform, the intensity relationship of the diffraction pattern could be computed without hesitation from the geometric data of the lattice according to the known formulas (compare for example [38]). The measurement of the wire thickness and the clearance was obtained with an ocular micrometer at the flash comparator, twice each time both the lattice itself and a photographic contact print were determined. In order to minimize the danger of systematic errors during measurement, the contrast between wire and clearance was kept as low as possible by suitable illumination. The cross-hair of the micrometer was turned by 45° against the wire edging, so that the thickness of the measuring line did not enter into the measurement. The result of the two measurements is at average, when m_0, m_z and m_s designate the relative brightnesses of the image without lattice expressed in classes of magnitude, the central image, or the diffraction image:

	lattice	print	average
wire thickness d	1.0066	0.9978	1.0022
clearance s	0.9934	1.0022	0.9978
$m_z - m_0$	1^m520	1^m500	1^m510
$m_s - m_0$	2.480	2.480	2.480
$m_s - m_z$	0.966	0.980	0.970

That is, in spite of all precautions taken during measurement there still appeared a contrast effect of 4.4 μ compared to almost 30 μ for the measurement of the Goettingen lattice described in [38]. However, the result for the photometric lattice constants $m_s - m_z = 0^m976$ is accurate to $\pm 0^m01$ on average of positive and negative measurement, and thus is sufficient for the present demands for precision.

The stellar spectra are spread during exposure by a simple arrangement for facilitating and increasing the accuracy of the photometric evaluation. A 3 mm thick plane parallel glass plate was installed about 3 cm in front of the focal spot and could be periodically rotated to ±15° of normal to the path of radiation by a lever transmission control of an eccentric disc. In this way the focal picture sweeps uniformly back and forth through the photographic plate between two fixed limits within a few seconds. The spreading of the stellar spectra thus achieved could be varied at will between 0.1 mm and 0.4 mm by controlling the beam transmission; it was so chosen that during extinction exposures for a star of third magnitude with lattice, the required time of illumination did not exceed ten minutes, and spreading was between 0.2 mm and 0.3 mm according to the brightness of the star pair used and the atmospheric visibility. The danger that such variation of the air disturbance with the zenith distance would affect the optical density is practically avoided by this type of spreading. /3

Each set of observations consisted of four equally low exposures in the series order--zenith star, extinction star, extinction star, zenith star. Slight temporary variations of the visibility as well as all other temporary or local linear sources of error (variations of the plate and photometer sensitivity) rendered practically harmless by this symmetrical arrangement. The photometric evaluation of the spectra was made with the Zeiss photoelectric recording photometer. The aperture height was made equal to the half-width of the spectra for the recording in order to avoid edge effects and errors of guideways for the curved side spectra. The measurement of the recorded curves and the further processing closely followed the methods used at Goettingen, so we can forego their description [38]. The reduction was facilitated considerably since the brightness difference to be photographically bridged could be kept very small by the appropriate choice of star pairs. It generally amounted to under $0^{m}.3$ and only in a few cases reached $1^{m}.0$. Therefore the reduction could always be followed by the convenient Hertz jump [Note: possibly square wave] formula.

The data of the usable extinction determinations carried out at Jena are summarized in Table 1. The extinction exposures were not restricted to particularly clear evenings, as shown by the description of the atmospheric condition for the individual observations, but were extended to atmospheric conditions with marked turbidity, during which there normally would not have been any photometric studies. During these exposures we tried to ensure by visual estimation that the condition of the sky was uniform in the various zenith distances. A few observations, for which there was a subsequent greater difference between the two exposures of the same star, were excluded from the treatment. The barometer reading *b* and vapor tension *e* data given in Table 1 were interpolated from the closing observations of the secondary meteorological station connected with the observatory.

TABLE 1. EXTINCTION OBSERVATIONS AT JENA.

No.	Date	Zenith star	Ext. star	sec z_1	sec z_2	Δ sec z	b (mm Hg)	e (mm Hg)	Atmospheric condition
1	1941 Aug 17	δ Cygn	α CorB	1.020	2.082	1.062	746	12.0	Exceptionally good
2	Aug 27	δ Cygn	α CorB	1.011	1.875	0.864	750	8.3	Good
3	Sep 14	δ Cygn	α CorB	1.009	1.801	0.792	758	7.5	Clearing after haze
4	Sep 24	δ Cygn	α CorB	1.008	1.740	0.732	752	10.2	Noticeable haze
5	1942 Apr 23	β UMaj	α CorB	1.006	1.771	0.765	746	4.8	Moderate
6	Jul 4	δ Cygn	α Andr	1.013	1.940	0.927	749	9.8	Fairly clear
7	Aug 11	δ Cygn	α CorB	1.010	2,006	0,996	746	10.2	Quite good
8	Aug 13	δ Cygn	α CorB	1.014	1.927	0.913	748	8.6	Very good
9	Aug 17	δ Cygn	η UMaj	1.009	1.635	0.626	752	11.3	Moderate
10	Aug 17	δ Cygn	α Andr	1.015	1.462	0.447	752	11.2	Moderate
11	Aug 18	δ Cass	β Auri	1.045	1.918	0.873	749	10.1	Good
12	Aug 19	δ Cass	β Auri	1.058	2.050	0.992	747	11.6	Fairly good
13	Sep 5	δ Cass	β Auri	1.057	2.032	0.975	748	12.2	Quite good
14	Sep 11	δ Cass	β Auri	1.032	1.763	0.731	753	12.0	Fairly good
15	Dec 4	δ Cass	β Auri	1.045	1.916	0.871	754	3.0	Good, fog on horizon
16	Dec 11	δ Pers	α Andr	1.113	2.107	0.994	748	4.4	Light valley fog
17	1943 Feb 25	θ Auri	c UMaj	1.031	1.764	0.733	753	4.0	Strong ground haze
18	Feb 28	θ Auri	ε UMaj	1.031	1.815	0.784	762	4.6	Moderate valley fog

The values for the extraterrestrial brightness differences Δm_0 used for the extinction determination of the star pair were taken from the results of the Goettingen spectral photometric work [19]. Inasmuch as the spectral exposures were obtained with nearly the same dispersion at Goettingen and at Jena, and the workup and particularly the measurement of the recorder curves were followed by the same procedure, and in part by the same observer, differences in conception of the continuous spectrum are not to be suspected, particularly since only star pairs of the spectral types B and A were used for the extinction determination.

The balanced values of the monochromatic magnitude classes m_λ taken from Tables 14 and 15 of the Goettingen publication 50, and based on the average of the Ao stars were used for all observations, as well as the differences formed from the star pairs used at any time and the values $\Delta m_0(\lambda)$ for the wavelengths measured at Jena interpolated from a graphic average formation of both systems S and T.

The monochromatic extinction coefficients k_λ were determined for the individual observations from the combination of above values Δm_0 with the observed brightness differences Δm_z and the path length differences Δsec z known from the observation time; the results are reproduced in Table 2 without any refinement. Inasmuch as the average error of the Goettingen values Δm_0 amounts to no more than 0^m2 and the uncertainty of the Jena measurements are estimated at about 0^m03 due to the favorable circumstances, the purely photometrically induced average error (which ordinarily has a value of k of the order of magnitude 1 derived from a path length difference) may be estimated at about 0^m04. The systematic accuracy is guaranteed mainly by the photometric scale of the Goettingen spectral photometry, which is certified by several independent calibrations to at least 0.01. The uncertainty of the Jena lattice constants does not practically enter into the results because of its slight bridging of the brightness differences. The errors which can arise in the extinction coefficients by the varying visibility at great and close zenith distance are difficult to grasp numerically; they can be eliminated by averaging the results from different nights.

TABLE 2. OBSERVED MONOCHROMATIC EXTINCTION COEFFICIENTS

λ	1/λ	1	2	3	4	5	6	7	8	9
.6536	1.530	0.24	0.36	[illegible]	0.72	0.17	0.31	0.22	0.25	[illegible]
.6369	1.570	0.27	0.37	0.28	0.76	0.27	0.32	0.25	0.36	0.37
.6215	1.609	0.28	0.37	0.27	0.82	0.37	0.33	0.26	0.34	[illegible]
[illegible]	1.648	0.31	0.40	0.28	0.87	0.30	0.38	0.30	0.32	0.31
[illegible]	1.686	0.35	0.45	0.37	[illegible]	[illegible]	0.40	0.34	0.35	[illegible]
[illegible]	1.725	0.37	0.45	0.40	0.80	0.44	0.42	0.32	0.35	[illegible]
[illegible]	1.75?	0.37	0.50	0.43	[illegible]	0.45	[illegible]	0.35	0.30	[illegible]
[illegible]	1.765	0.37	0.40	[illegible]	[illegible]	0.51	0.40	0.35	0.35	[illegible]
[illegible]	1.8?0	0.37	0.49	0.43	1.00	0.51	0.46	0.35	0.42	[illegible]
[illegible]	1.865	0.30	0.49	0.43	1.05	0.53	0.40	0.31	0.42	[illegible]
[illegible]	1.897	0.40	0.51	0.48	[illegible]	0.50	0.50	0.35	0.43	0.70
[illegible]	1.930	0.41	0.53	0.50	1.05	0.59	0.45	0.36	[illegible]	0.76
[illegible]	[illegible]	0.43	0.50	0.52	1.08	0.63	0.49	0.37	0.46	0.80
[illegible]	[illegible]	0.45	0.57	0.52	1.12	0.65	0.51	0.40	[illegible]	0.83
[illegible]	2.022	0.40	0.59	0.54	[illegible]	0.68	0.51	0.41	0.45	0.85
[illegible]	2.052	0.47	0.59	0.58	[illegible]	0.66	0.54	0.45	0.53	0.88
[illegible]	[illegible]	0.51	0.61	0.62	1.17	0.71	0.50	0.46	0.54	[illegible]
[illegible]	2.111	0.52	0.64	0.61	1.23	0.71	0.57	0.47	0.56	[illegible]
[illegible]	2.139	0.51	0.62	0.56	1.24	0.72	0.58	0.46	0.58	[illegible]
.4615	2.167	0.51	0.66	0.62	1.26	0.74	0.59	0.52	0.58	[illegible]
.4558	2.194	0.54	0.71	0.66	1.28	0.76	0.63	0.54	[illegible]	[illegible]
.4505	2.220	0.54	0.72	0.68	1.30	0.76	0.64	0.58	0.65	1.01
.4454	2.245	0.55	0.72	0.70	1.31	0.77	0.66	0.58	[illegible]	[illegible]
.4403	2.271	0.57	0.73	0.72	1.38	0.76	0.67	0.66	0.69	1.04
.4355	2.296	0.58	0.75	0.73	1.41	0.80	0.67	0.62	0.70	1.06
.4310	2.320	0.60	0.75	0.75	1.41	0.80	0.68	0.64	0.71	1.12
.4266	2.344	0.61	0.78	0.77	1.45	0.82	0.68	0.65	0.73	1.15
.4225	2.367	0.63	0.80	0.77	1.46	0.88	0.70	0.66	0.74	1.17
[illegible]	[illegible]	[illegible]	0.81	0.80	[illegible]	0.93	0.71	[illegible]	0.76	[illegible]
[illegible]	2.412	[illegible]	0.83	0.83	1.54	0.94	0.74	0.72	0.78	1.20
[illegible]	2.434	0.70	0.84	[illegible]	1.50	0.98	[illegible]	0.73	0.80	1.21
[illegible]	2.450	0.72	0.86	[illegible]	1.57	1.01	0.76	0.74	0.82	[illegible]
[illegible]	2.478	0.72	[illegible]	[illegible]	1.58	1.02	[illegible]	0.76	0.83	1.23
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.02	[illegible]	[illegible]	0.84	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.03	[illegible]	0.82	0.83	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2.550	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.82	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.82	[illegible]	0.94	1.78	1.12	0.80	0.83	0.87	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.22	[illegible]	—	—	—	0.83		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			—	—		[illegible]

TABLE 2. (Continued) /5

λ	1/λ	10	11	12	13	14	15	16	17	18
[illegible]	1.530	0.31	0.32	0.44	0.32	0.40	0.21	0.15	0.65	0.33
[illegible]	1.570	0.40	0.36	0.41	0.34	0.50	0.26	0.19	0.73	0.45
[illegible]	[illegible]	0.43	0.32	0.43	0.35	0.55	0.31	0.21	0.70	0.47
[illegible]	1.638	0.53	0.45	0.49	0.41	0.57	0.32	0.25	0.80	0.52
[illegible]	1.680	0.57	0.47	0.57	0.42	0.56	0.32	0.25	0.84	0.56
[illegible]	1.723	[illegible]	0.47	0.53	0.47	0.60	0.37	0.29	0.87	0.60
[illegible]	1.750	0.81	0.49	0.50	0.47	0.63	0.37	[illegible]	0.84	0.56
[illegible]	1.765	0.78	0.49	0.56	[illegible]	0.63	0.37	0.35	0.86	0.57
[illegible]	1.810	0.81	0.50	0.60	[illegible]	0.61	0.38	0.32	0.90	0.57
[illegible]	1.863	0.87	0.52	0.60	0.52	0.63	0.40	0.32	0.93	0.60
[illegible]	1.897	0.87	0.46	0.60	0.51	0.62	0.38	0.34	0.91	0.62
[illegible]	1.930	0.90	0.50	0.60	0.52	0.63	0.39	0.30	0.94	0.64
5100	1.961	0.96	0.50	0.62	0.52	0.62	0.39	0.30	0.98	0.66
5022	1.992	[illegible]	0.54	0.64	0.55	0.63	0.39	0.28	1.00	0.66
49[illegible]	2.022	0.94	0.53	0.64	0.50	0.67	0.38	0.34	1.01	0.66
[illegible]873	2.052	0.92	0.56	0.69	0.60	0.72	0.38	0.34	1.02	0.66
[illegible]	2.082	1.01	0.61	0.71	0.61	0.72	0.46	0.39	1.04	0.69
[illegible]737	2.111	1.03	0.65	0.74	0.64	0.77	0.47	0.40	1.07	0.71
[illegible]	2.139	1.08	0.65	0.75	0.64	0.78	0.48	0.42	1.11	0.73
[illegible]615	2.167	1.12	0.68	0.77	0.67	0.81	0.52	0.42	1.12	0.75
[illegible]	2.194	1.16	0.70	0.78	0.69	0.85	0.53	0.43	1.14	0.75
4505	2.220	1.16	0.71	0.80	0.70	0.88	0.54	0.45	1.12	0.78
[illegible]	2.245	1.16	0.73	0.81	0.72	0.93	0.54	0.46	1.15	0.80
[illegible]	2.271	1.16	0.76	0.83	0.74	0.94	0.54	0.47	1.17	0.80
4355	2.296	1.21	0.78	0.85	0.76	0.98	0.57	0.48	1.21	0.83
[illegible]	2.320	1.23	0.81	0.88	0.77	0.98	0.59	0.50	1.22	0.84
[illegible]	2.344	1.28	0.82	0.90	0.78	1.07	0.61	0.51	1.25	0.84
[illegible]	2.367	1.32	0.83	0.92	0.79	1.07	0.63	0.51	1.25	0.85
[illegible]	2.389	1.32	0.86	0.95	0.81	1.08	0.63	0.51	1.26	0.88
[illegible]	2.412	1.34	0.89	0.99	0.82	1.09	0.66	0.53	1.31	0.91
[illegible]	2.434	1.34	0.90	1.00	0.85	1.12	0.68	0.56	1.32	0.92
[illegible]	2.456	1.32	0.92	1.01	0.86	1.15	0.69	0.57	1.32	0.92
[illegible]	2.478	1.32	0.93	1.04	0.89	1.15	0.72	0.60	1.33	0.92
[illegible]	[illegible]	[illegible]	0.97	1.07	0.86	[illegible]	0.74	0.60	1.35	0.96
[illegible]	[illegible]	[illegible]	0.90	1.05	0.88	1.14	0.72	0.59	1.30	0.97
[illegible]	[illegible]	[illegible]	0.95	1.05	[illegible]	[illegible]	0.75	0.59	1.39	0.97
[illegible]	[illegible]	[illegible]	[illegible]	1.07	[illegible]	1.14	0.76	[illegible]	1.39	0.98
[illegible]	2.580	[illegible]	0.96	[illegible]	[illegible]	[illegible]	0.75	0.62	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.98	1.10	[illegible]	[illegible]	0.77	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.97	1.14	[illegible]	—	0.77	[illegible]	[illegible]	1.05
[illegible]	[illegible]	[illegible]	1.03	1.11	0.97	—	[illegible]	[illegible]	1.50	1.07
[illegible]	2.657	1.38	1.11	1.19	0.98	—	0.67	[illegible]	1.50	1.10
[illegible]	2.675	1.23	1.12	—	1.22	—	0.76	0.72	1.50	[illegible]
3713	2.693	1.43	—	—	1.19	—	—	0.77	—	—
3690	2.710	1.60	—	—	1.28	—	—	0.71	—	—

5. The Gradients of the Extinction Coefficients and Their Correlation with Visibility

A linear statement of the form

$$k_\lambda = k_0 + g\left(\frac{1}{\lambda} - 2.0\right)$$

can serve as the first approximation for the wavelength dependence of the extinction, which directly yields the extinction factor A = 0.921 g for the reduction of the observed gradients from the color temperatures. The values of the spectral g derived from 18 observations at Jena by calculated equalization in the spectral range 400 mμ $< \lambda <$ 640 mμ, and the extinction coefficients k_0 for the wavelength 500 mμ are given in Table 3. The average deviation from the observed monochromatic extinction coefficient from the linear representation amounts to only $\pm^{m}_{\cdot}032$; the average error of a gradient obtained from this comes to ±0.02. Table 3 further shows the values for the visual extinction coefficients k_v determined from the linear interpolation formula, corresponding to the wavelength 500 mμ, and the values for the photographic extinction at 430 mμ. /6
It may be seen from the values of k_v that the visibility at Jena is generally rather poor; visual extinction values of $0^{m}_{\cdot}3$, which may be considered a normal average for other locations, may only be observed in the clearest nights. Inasmuch as the visual extinction coefficient in a non turbid atmosphere amounts to roughly $0^{m}_{\cdot}1$, the visual turbidity factor attains a value of 3 to 10 for the measurements at Jena. This material of observation is therefore particularly well suited for a systematic investigation of the extinction behavior for different degrees of turbidity.

Because of the pronounced turbidity, the spectral gradient of the extinction coefficient is also appreciably greater for the measurements at Jena than for other observatories from which spectral photometric extinction determinations are available. At Jena we obtained for the coefficient A - 0.921 g an average of 0.580 with an average deviation of ±0.133, while the corresponding value for other observatories, according to the summary in Table 4, is always between 0.3 and 0.5. These gradients, however, are not strictly comparable among themselves, since they are dependent on the limitation of the spectral range employed and, to a certain extent, even on the distribution of the chosen wavelengths within this range. The comparison of the extinction at different locations, therefore, is given later (Section 8) on the basis of a better description.

TABLE 3. GRADIENTS AND VALUE OF INDIVIDUAL EXTINCTION COEFFICIENTS

No.	g	k_u	k_v	k_{pg}
1	0.471	[illegible]	0.378	[illegible]
2	0.554	0.589	0.489	[illegible]
3	0.698	0.546	[illegible]	[illegible]
4	0.872	1.144	0.987	[illegible]
5	0.718	0.631	0.502	0.894
6	0.481	0.527	[illegible]	[illegible]
7	0.567	0.450	0.345	[illegible]
8	0.611	0.512	0.402	[illegible]
9	0.898	0.825	[illegible]	[illegible]
10	0.808	[illegible]	0.783	1.237
11	0.612	[illegible]	[illegible]	1.799
12	0.644	[illegible]	0.508	1.803
13	[illegible]	0.582	0.480	[illegible]
14	[illegible]	0.750	0.520	[illegible]
15	[illegible]	0.447	0.364	1.597
16	0.405	0.304	[illegible]	[illegible]
17	[illegible]	1.010	[illegible]	[illegible]
18	0.515	0.673	0.380	0.820
Average value	0.636	0.652	0.536	0.857
Average deviation	±0.134	±0.205	±0.185	±0.244

TABLE 4. GRADIENTS OF EXTINCTION AT VARIOUS LOCATIONS.

Location	A	k_v	Observer
Ann Arbor (Mich.)	0.30	--	R. C. Williams [39]
Babelsberg	0.30	0.21	W. Becker [5]
Cambridge (Mass.)	0.54	--	B. P. Gerasimovic [10]
Goettingen	0.31	0.11	
	0.40	0.26	J. Wempe [38]
	0.62	0.60	
Greenwich	0.32	--	W. M. H. Greaves et al. [16]
Kiel	0.38	0.33	H. Jensen [17]
Potsdam	0.26	0.23	G. Müller [30]
	0.31	--	J. Wilsing [41]
	0.32	0.29	J. Wilsing [42]
Washington	0.36	0.34	C. G. Abbot et al. [1]

The individual values of g and k_v from 18 Jena determinations show a close connection, as is to be expected. The correlation coefficient amounts to r = = +0.80 ± 0.08. The graphic representation of this statistical relation (Figure 1) shows, in addition to the regression line $g = 0.325 + 0.565\ k_v$, another straight line, which is derived from the law of the fog extinction (Section 7). The gradient of groups of varying visibility from the Goettingen observations (the average of three of which are reported in [38], extrapolated to the whole spectral range of 400 mμ < λ < 650 mμ, are shown as open circles in Figure 1; they fit in well, along with the results of a few other observations /7 (Table 4), with the relation to the visual extinction derived from the Jena measurements, although more accurate investigation (compare Section 9) disclosed systematic differences between the extinction at Goettingen and at Jena. The practical conclusion follows from this that a considerably more accurate regard for the extinction can be reached for spectral photometric observations even with the slight effort of carrying out a visual extinction determination, or by a mere estimation of the visibility, than by the use of average extinction coefficients. On the other hand, the often raised or expressed demand for an individual spectrophotometrical extinction determination is shown to be exaggerated, at least for the derivation of relative gradients.

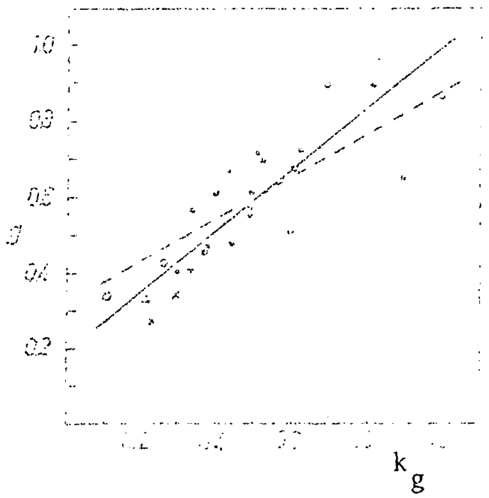

Figure 1. Correlation of the Spectral Gradients g with the Visual Extinction k_g.o Individual Observations at Jena; o, Group average Goettingen; Δ Average value Babelsberg; + Average value Kiel; x, Average values Potsdam; ---, Regression line at Jena observations; ——, Exponential equation for fog extinction (α = 1.5).

4. The Separation of the Various Extinction Components.

The attenuation of light in the terrestrial atmosphere is influenced by three different phenomena:

1. scattering on the molecules of the permanent gases;
2. line and band absorption by the various constituents;
3. scattering and absorption by haze particles (fog).

For the first component, the law of dependence on wavelength is known, and the amount of extinction may be obtained from theoretical considerations (Rayleigh scattering). The question of an empirical test of the theory depends on whether the other components of the observed total extinction can be separated satisfactorily. The second component, the selective extinction, may be recognized without further effort at the spectral resolution, insofar as the absorption is of decided line or band character and the resolving power is sufficient. This is the case, for example, for the narrow bands of oxygen at 687 mμ, as well as the numerous strong bonds of water vapor in the long wave spectral range. The separation of the expanded ultraviolet band of ozone is more difficult and can be left out at this time since it is outside the normally considered spectral range. The weak Chappuis band of ozone in the visible range between 450 mμ and 700 mμ is not ordinarily resolved for spectral photometric purposes by the use of slight dispersion. The absorption activated by it is thus made applicable as continuous extinction and cannot be separated from the other components without further ado. This also applies to the numerous fine water vapor lines which are particularly accumulated around the wavelengths 590 mμ to 650 mμ, 660 mμ, and 700 mμ.

The empirical possibility of separation from the other components is controversial for the continuous extinction caused by the diffusion of the water content of the atmosphere. For the spectral bolometric recording of the solar spectrum on Mt. Wilson (1,730 m) F. E. Fowles [9] attempted a separation of the water vapor component (transmission coefficient p_w) of the extinction of the dry atmosphere (transmission coefficient p_a) by the trial solution $p = p_a p_w^w$, or expressed in extinction coefficients $k = k_a + wk_w$, where w indicates the total water vapor content of the atmosphere as thickness of an equivalent layer of water, determined at the same time from the band absorption. It was pointed out by F. Linke [25] that this procedure would yield an extrapolation to a fog-free atmosphere only when the water vapor content was strictly correlated with the fog mass encompassing all turbidity-forming particles. However, this is certainly not the case at least for the observation stations at low altitude. Thus, for example, the extinction coefficients k_0 observed at Jena show no correlation worth mentioning ($r = + 0.16 \pm 0.23$) with the ground vapor pressure e, which, at least statistically, is linearly related to the total water vapor content ω of the atmosphere. Of course, an empirical linear relationship appears to have been obtained by Fowle, for observations at greater altitude, between the observed monochromatic extinction coefficients and the water vapor content. Still, F. W. P. Goetz [15] obtained a separation of the two extinction components which deviated significantly from the Fowle result. This was carried out with the same and further material of observation (Mt. Wilson and Montezuma), in any case with the ground vapor pressure as a parameter for the water content of the atmosphere, by a non-linear graphic extrapolation. The water vapor extinction, or fog extinction, respectively, can thus not be separated unambiguously from the extinction of the non turbid atmosphere by a purely empirical procedure. The only possibility left, therefore, is to derive the extinction value arising from the permanent gases by other ways and to determine the variable component of the fog extinction as difference against the observed total extinction.

5. Calculation of the Extinction by Molecular Scattering /8

The law of scattering of light on small particles just developed by Rayleigh (compare, for example [26]) is valid for the transmission coefficient $p_R = e^{-a}$ of a non turbid atmosphere of the homogeneously reduced altitude H under normal pressure (760 mm)

$$a = \frac{32\pi^3(n-1)^2 H}{3N\lambda^4},$$

where λ is the wavelength, n--the diffraction index, and N--the number of scattering particles in a unit of volume. J. Cabannes [6,7] abandoned the simplifying assumption of a spherical shape for the scattering particles, (because experience could not confirm the conclusion of the Rayleigh theory that scattered light is completely polarized below 90°) and introduced an optical anisotropy of the molecule, which resulted in a correction for the Rayleigh coefficient $a(\lambda)$ by the factor

$$C = \frac{6+3\rho}{6-7\rho}.$$

The constant ρ is obtained from the laboratory determination of the degree of polarization [6] for atmospheric air of $\rho = 0.042$, the factor C is therefore 1.073. While this elaboration of the Rayleigh theory, along with the consideration of the secondary diffusion could clear up the incomplete polarization of the atmospheric scattered light, according to J. J. Tichanowsky [35], difficulties arose through the introduction of the anisotropy factor C for the representation of the observed extinction coefficient. Cabannes [7] was forced to figure with a particle number per unit volume ($N = 2.91 \times 10^{19}$) during a discussion of the extinction coefficient for dry air derived by Fowle, which was in contradiction with all other determinations of the Avogadro number, while the original Rayleigh formula came very close to the correct value ($N = 2.70 \times 10^{19}$). Of course, T. Kiu [20] later derived a plausible value for N, namely $(2.74 \pm 0.04) \cdot 10^{19}$, by introducing a Rayleigh extinction term from water vapor (along a neutral component) and with the retention of the anisotropy factor. T. W. P. Goetz [15], as already mentioned, found extinction values for the dry atmosphere by a nonlinear reduction of the water vapor component, which could be somewhat better represented in the visible spectral range with the use of the Cabanne factor than without it. On the whole, however, it seems that an informal interpretation of the extinction observations by the original Rayleigh formula might be better; an indirect conclusion to be reported later (Sections 8 and 9) also speaks against the introduction of the correction factor. Therefore, the monochromatic transmission coefficients $p_R = e^{-a}$ and the corresponding extinction coefficients $k_R = 1.083\ a_\lambda$ for a clear non turbid atmosphere expressed in class magnitudes, were computed without the anisotropy factor with the constant $H = 7.991$ km and $N = 2.70 \cdot 10^{19}$ cm^3. For /9 the course of the diffraction exponent n with the wavelength there were used values obtained by T. Kiu [2] by a graphic equalization of numerous older determinations combined into an average value with one derived by Meggers and Peters [27] from an interpolation formula by systematic measurements.

The calculated values of p_R and k_R obtained in this way are reproduced in Table 5 for the convenient interpolation at narrow intervals.

6. The Absorption of Ozone in the Visible Spectral Region

The optical layer density of ozone occurring predominantly in the higher atmospheric layers are generally determined from the strong bands in the ultraviolet; it amounts to an average of about 3 mm. This value is subject to a systematic variation with the geographical latitude (minimum of about 2 mm at the equator) and irregular local and temporary fluctuations. It also shows an

TABLE 5. RAYLEIGH EXTINCTION COEFFICIENT k_R AND TRANSMISSION FACTOR p_R FOR 760 mm PRESSURE.

λ	k_R	p_R	λ	k_R	p_R	λ	k_R	p_R	λ	k_R	p_R
300 mμ	1ᵐ237	0.3201	400 mμ	0ᵐ367	0.7130	500 mμ	0ᵐ146	0.8738	700 mμ	0ᵐ037	0.9661
305	1.152	0.3462	405	0.349	0.7253	510	0.135	0.8830	720	0.033	0.9696
310	1.074	0.3719	410	0.331	0.7370	520	0.125	0.8914	740	0.030	0.9728
315	1.003	0.3972	415	0.315	0.7482	530	0.116	0.8991	760	0.027	0.9756
320	0.938	0.4215	420	0.300	0.7587	540	0.107	0.9061	780	0.024	0.9780
325	0.878	0.4454	425	0.286	0.7687	550	0.099	0.9125	800	0.022	0.9801
330	0.823	0.4687	430	0.272	0.7782	560	0.092	0.9185	850	0.017	0.9844
335	0.772	0.4910	435	0.260	0.7874	570	0.086	0.9239	900	0.014	0.9876
340	0.725	0.5127	440	0.248	0.7961	580	0.080	0.9289	950	0.011	0.9900
345	0.682	0.5336	445	0.236	0.8044	590	0.075	0.9335	1000	0.009	0.9918
350	0.642	0.5538	450	0.226	0.8124	600	0.070	0.9377	1200	0.004	0.9961
355	0.605	0.5730	455	0.216	0.8200	610	0.065	0.9416	1400	0.002	0.9979
360	0.570	0.5914	460	0.206	0.8272	620	0.061	0.9452	1600	0.001	0.9988
365	0.538	0.6091	465	0.197	0.8340	630	0.057	0.9486	1800	0.001	0.9992
370	0.508	0.6261	470	0.188	0.8406	640	0.054	0.9517	2000	0.001	0.9995
375	0.480	0.6424	475	0.181	0.8468	650	0.051	0.9545	2500	0.000	0.9998
380	0.454	0.6580	480	0.173	0.8526	660	0.048	0.9572	3000	0.000	0.9999
385	0.430	0.6727	485	0.166	0.8584	670	0.045	0.9597	4000	0.000	1.0000
390	0.408	0.6868	490	0.159	0.8637	680	0.042	0.9620	5000	0.000	1.0000
395	0.387	0.7003	495	0.153	0.8689	690	0.040	0.9641	6000	0.000	1.0000

annual progress (maximum in the spring), whose amplitude at high latitudes amounts to about ±20%. According to the results summarized by F. W. P. Goetz [11], the density of the ozone layer in relation to position and time may generally be given with an accuracy which is sufficient for the estimation of relatively weak ozone absorption in the visible spectral range.

There are two independent determinations for the absorption coefficients of ozone in the region of the Chappuis bands. The measurements of G. Colange [8] chemically determined the amount of ozone contained in three absorption tubes of a combined length of 6 m (optical density 18 cm), while A. Vassy [36] determined the effective amount of ozone (7 cm to 26 cm) for his measurement spectrographically under the assumption of the ultraviolet absorption coefficients determined by Ny Tsi-Ze and Choong Shin-Piaw. The results of the two investigations are reproduced in Figure 2 in such a manner that besides the decade-expressed absorption coefficients a per mm, the extinction may also be read off in class magnitudes for a layer thickness of 3 mm in relation to the wavelengths. A variation of up to 30% in the maxima of the two measuring series may be connected with the use of very different dispersions (32Å/mm for Vassy, about 100 Å/mm for Colnage). A similar difference is also present with regard to the temperature dependence of the absorption coefficients; while Vassy [37] determined an increase in absorption by 20% to 50%, when the temperature was reduced to -100° in connection with the measurements of Colange (which were set up at room temperature), L. Lefebvre [22] found no marked temperature effect for the Chappuis bands. Since a temperature of about -35°C is to be assumed [4] for the principal mass of atmospheric ozone on the basis of the observed temperature effect for the Huggins bands, the absorption coefficients of Colange should be increased by about 10% based on the findings of E. Vassy. These values were assumed for the determination of the ozone absorption in the atmosphere; the remaining uncertainty in comparison with the observation accuracy of the total extinction is not serious due to the slight absolute amount.

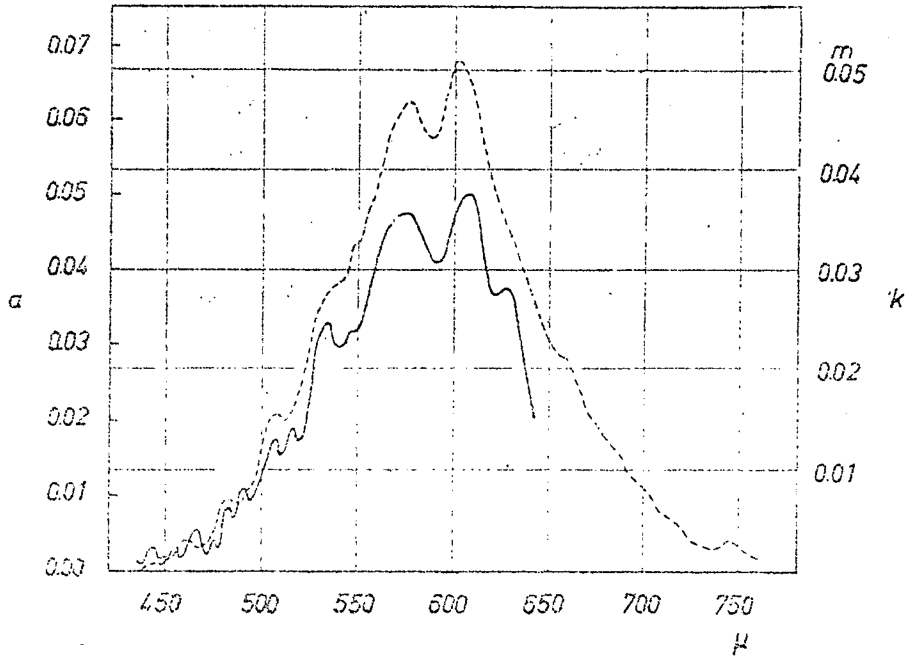

Figure 2. Chappuis Bands of Ozone. ——, According to A. Vassy, ----, according to G. Colange. a, Decode absorption coefficient per mm; k, Extinction in class magnitude through 3 mm ozone.

7. The Wavelength Dependence of the Fog Extinction According to the Observations at Jena

The fog extinction k_D was derived from the observed amounts of extinction k_λ (Table 2) by subtraction of the Rayleigh extinction k_R according to Table 5 (multiplied for the barometer level b with $b/760$) and the ozone absorption k_{O_3} according to Figure 2. To simplify the further computation and to balance out the errors of observation, the 18 individual measurements were here assembled into three groups, which were limited as follows according to the observed average extinction k_o:

Group	k_o	Observation No.
I	<0.53	1, 6, 7, 8, 15, 16
II	0.53 to 0.68	2, 3, 5, 11, 13, 18
III	>0.68	4, 9, 10, 12, 14, 17

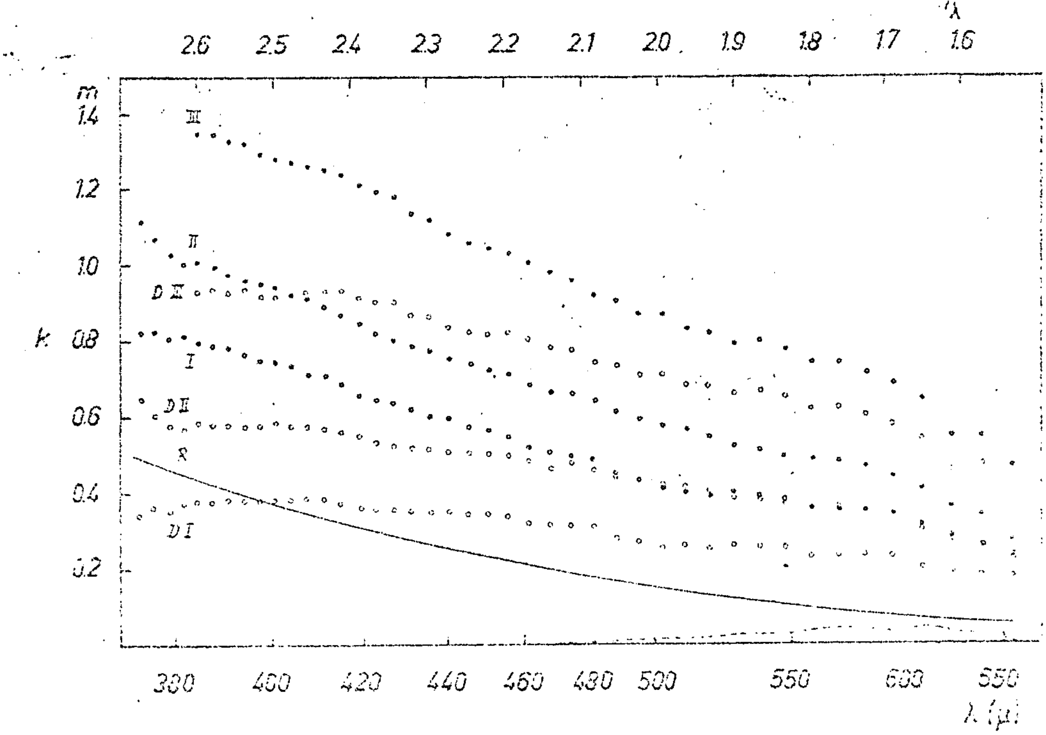

Figure 3. Extinction Observations at Jena, Determined According to the Optical Visibility (I, II, III). o, Observed extinction coefficients; 0, Fog extinction; ——, Rayleigh extinction; ----, Ozone absorption.

The course of the fog extinction and the observed total extinction for these three groups along with the Rayleigh extinction and the ozone absorption are represented in Figure 3. It may be seen from this that the fog extinction increases considerably less toward the shorter wavelengths than the Rayleigh component; at about 400 mμ k_D becomes almost constant and even almost goes somewhat back into the ultraviolet. A decreasing fog extinction, the other side of 400 mμ, was also determined by F. W. P. Goetz [12] from measurements on a terrestrial basis.

In analogy to the Rayleigh formula $k_R \sim I/\lambda^4$, the mathematical expression $k_D \sim I/\lambda^\alpha$ approximates an interpolative representation of the extinction coefficient k of the fog. On theoretical grounds it is, of course, not to be expected that this expression would be strictly valid in a greater wavelength range. For the scattering on pure water small spheres of certain size, the computations of Stratton and Haughton [34], carried out on the basis of the Debye-Miesch theory, do not give a monotonic development of the extinction coefficient with the wavelength, but rather the existence of a decided maximum at a wavelength which is approximately equal to the radius of the droplet. On the long wave side of this maximum, an approximate representation of the extinction development appears to be possible by a power of the reciprocal wavelength, while on the short wave side, according to the presentation of F. W. P. Goetz [13], the exponent α changes fast with the wavelength and can also assume a negative value. When mixing water droplets of various sizes, a certain balancing may be expected by the overlapping of the maxima from the individual droplet diameters, even if the examples calculated by F. Linke [25] do not yet /11 show any approach to a monotonic development. A direct application of such theoretical discussions about fog extinction has the disadvantage that the natural fog particles do not consist of pure water droplets, but are always attached to solid condensation nuclei. As a further constituent of atmospheric fog for low moisture, solid particles (dust) must be considered, whose spectral extinction development is characterized (according to the calculations of F. W. P. Goetz [14] by an almost sudden transition from the Rayleigh scattering ($\alpha = 4$) to neutral absorption ($\alpha = 0$) with an increase of the particle radius ρ to the value $\rho/\lambda = 0.16$, while, according to the experimental results of F. Linke and H. V. D. Borne [24] this transition is extended to a range of at least two powers of ten in the particle radius (10^{-16} to 10^{-4} cm) within which the wavelength exponent α varies monotonically with the particle size. Therefore, the exponential equation for the fog extinction can generally be evaluated only for an interpolative representation, whose physical interpretation by the combination of the exponent α with the particle size requires a knowledge of the composition of the fog.

The representation of the transmission coefficient p_D for fog in the form

$$p_D = e^{-\frac{\beta}{\lambda^{\alpha}}}$$

was used by A. Ångstrom [3] for the definition of the turbidity coefficient β as a measure of the total turbidity mass contained in the atmosphere. Under retention of these designations which are familiar in meteorological literature, the extinction coefficient expressed class magnitudes becomes

$$k_D = 1.086 \frac{\beta}{\lambda^{\alpha}} .$$

The constants α and β are most simply obtained graphically or by calculation from the empirical values of k_D by the linear relation

$$\log k_D = -\alpha \log \lambda + \log \beta + 0.036 .$$

A class description (for astronomical concepts) of the degree of atmospheric turbidity is obtained, when instead of the turbidity coefficient β of Ångstrom, the zenithal fog extinction for a certain wavelength, expressed in class magnitudes, for example $\lambda = 550$ mμ, is introduced. In the following this magnitude is indicated under the designation "visual fog extinction" $K_D = 1.086\ (1.818)^{\alpha}\ \beta$, by the turbidity coefficient β.

The constants α and β were determined by calculated equalization of log k_D in the spectral range 410 mμ $< \lambda <$ 650 mμ, with the use of the above designations for the observations at Jena. Due to the steeply rising optical density, the first measuring point at the red end at 654 mμ was excluded because the photometric evaluation is unsure for the type of plate used (Agfa Isopan ISS) at this point. The limitation at the short wave end was undertaken because of the expected systematic deviation from the interpolative equation. For the constants α, β and K, the following values were obtained for the three optical visibility groups:

	α	β	K
I	1.52±0.06	0.090±0.004	$0^{m}.244$
II	1.56±0.05	0.132±0.002	0.364
III	1.46±0.05	0.239±0.001	0.622

The computation was also tried with the Cabanne formula for the molecular extinction: the result in that case is $\alpha_{I} = 1.42$; $\alpha_{II} = 1.49$; $\alpha_{III} = 1.42$.

This result is remarkable in that in spite of the great variation in visibility for all three groups the same value is obtained for exponent α, on the average $\alpha = 1.515 \pm 0.05$. From this it may be concluded that the mixing ratio of the various particle sizes contained in the fog does not vary appreciably with the increase in turbidity, since we are dealing with substantially the same composition of the fog (water droplets) within the turbitidy range of the observations.

The quality of the representation of the fog extinction by the exponential equation may be judged from Table 6, which shows, besides the observed total extinction from which the Rayleigh extinction (for 760 mm pressure) was subtracted and the attached ozone absorption, the values of the fog extinction for the three visibility groups and the remainder (observation-computation) obtained by the computation against the interpolative formula with the uniform exponent $\alpha = 1.50$. The average deviation in the spectral range considered for the equalization is only $\pm^{m}.010$; the largest positive remainder appears in the neighborhood of 580 mμ, where a reinforced extinction should be expected due to the bunching of many fine water vapor lines. Of course, at this location the ozone absorption is also particularly great and is determined with uncertainty. However, the increase in the remainder with the turbidity would indicate that the deviation is due to the water vapor. /12 The accuracy of this interpretation is also confirmed by the following estimation of the total amount of live absorption. When the lines are counted (according to their estimated intensity) which are explicitly ascribed to the atmospheric water vapor in the Rowland tables of the solar spectrum [18] and are recalculated in total absorption according to the calibration of the Rowland scale by Mulders [28], then there is obtained in a spectral range of 80.55 Å spread a summarized equivalent latitude of the non-resolved lines (Rowland intensity < 4) of 2.56 Å ; this corresponds to a depression of the continuous spectrum by $0^{m}35$, i.e., the exact order of magnitude of the remainder against the interpolation formula. When this region of selective absorption is excluded from the equalization during the determination of the constants α and β, then the wavelength exponent of the fog extinction is only slightly larger (average $\alpha = 1.55$).

The mathematical interrelationship that is found for the exponent α which is independent of the turbidity permits a convenient representation of the monochromatic extinction for various degrees of turbidity. If the total extinction is known from observation for any one wavelength λ_0, then the fog extinction $k_D(\lambda_0)$ is obtained by subtracting the Rayleigh extinction k_R according to Table 5 and the ozone absorption k_{O_3} according to Figure 2. From this we ob- /13
tain the fog extinction $k_D(\lambda)$ for any desired wavelength λ within the visible spectral range by $k_D(\lambda) = (\lambda_0/\lambda)a\ k_D(\lambda_0)$ and the total extinction by the addition of the molecular and ozone components.

The spectral gradients of the various extinction components may be assembled in the same manner. The following summary contains an illustration of the gradients of the Rayleigh extinction

$$g_R = \frac{d\,k_R}{d(1/\lambda)} = 4\,k_R\,\lambda ;$$

and the fog extinction

$$g_D = \frac{d\,k_D}{d(1/\lambda)} = \alpha\,k_D\,\lambda$$

for a few wavelengths and the visual fog extinction $K_D = 0^{m}20$:

λ	700	600	500	400 mμ
g_R	0.105	0.168	0.293	0.588
g_D	0.260	0.287	0.325	0.351

The gradient of the ozone absorption may be computed numerically for the chosen wavelengths. It amounts to $g_{O_3} = -0.045$, for example, in the range

400 mμ < λ < 650 mμ, for the scale used for the Jena observations, while the average gradient of the Rayleigh extinction in the same range amounts to g_R = = +0.337.

TABLE 6. FOG EXTINCTION FROM THE OBSERVATIONS AT JENA.

λ	k_R	k_{O_3}	k_D			Observation Calculation		
			I	II	III	I	II	III
6536	0.050	0.005	0.181	0.223	0.416	— 7	—60	— 60
6369	0.055	0.022	0.180	0.266	0.472	— 7	—28	— 22
6215	0.060	0.031	0.195	0.277	0.458	— 8	—28	— 55
6068	0.067	0.040	0.207	0.302	0.539	— 4	—15	+ 7
5931	0.073	0.033	0.235	0.338	0.583	+17	+10	+ 32
5804	0.080	0.037	0.237	0.356	0.601	+12	+18	+ 32
5685	0.087	0.037	0.235	0.365	0.622	+ 3	+16	+ 35
5571	0.094	0.032	0.233	0.363	0.622	— 7	+ 3	+ 17
5467	0.102	0.026	0.257	0.371	0.653	+10	+ 1	+ 23
5368	0.110	0.025	0.257	0.379	0.668	+ 4	— 1	+ 29
5273	0.118	0.024	0.260	0.387	0.657	0	— 4	0
5184	0.126	0.015	0.253	0.407	0.682	—14	+ 6	+ 8
5100	0.135	0.014	0.260	0.417	0.685	—14	+ 6	— 5
5022	0.144	0.013	0.257	0.425	0.717	—23	+ 4	+ 10
4946	0.153	0.009	0.270	0.433	0.712	—16	+ 3	— 11
4873	0.163	0.008	0.279	0.444	0.738	—14	+ 4	— 1
4803	0.173	0.005	0.312	0.466	0.747	+13	+16	— 8
4737	0.183	0.003	0.315	0.476	0.778	+ 9	+17	+ 7
4675	0.193	0.003	0.317	0.468	0.789	+ 6	0	+ 3
4615	0.203	0.003	0.320	0.483	0.808	+ 2	+ 5	+ 6
4558	0.214	0.002	0.335	0.498	0.823	+11	+12	+ 6
4505	0.225	0.002	0.343	0.500	0.820	+14	+ 5	— 11
4454	0.236	0.002	0.341	0.505	0.827	— 6	+ 2	— 19
4403	0.247	0.002	0.352	0.506	0.841	+11	— 6	— 19
4355	0.259	0.001	0.347	0.518	0.868	0	— 2	— 6
4310	0.270		0.354	0.520	0.873	+ 2	— 9	— 15
4266	0.281		0.355	0.524	0.905	— 2	—13	+ 3
4225	0.292		0.357	0.531	0.909	— 6	—14	— 7
4186	0.304		0.359	0.547	0.917	— 9	— 6	— 12
4146	0.316		0.374	0.557	0.932	+ 1	— 3	— 10
4108	0.328		0.382	0.568	0.934	+ 4	0	— 20
4072	0.341		0.381	0.575	0.930	— 2	— 1	— 37
4036	0.354		0.383	0.575	0.925	— 6	—12	— 55
4002	0.366		0.383	0.583	0.921	—10	— 7	— 71
3971	0.370		0.377	0.577	0.922	—21	—21	— 82
3939	0.393		0.378	0.573	0.930	—25	—32	— 77
3908	0.405		0.384	0.577	0.932	—24	—35	— 97
3871	0.419		0.375	0.583	0.938	—38	—37	—103
3846	0.432		0.373	0.581	0.931	—45	—46	—123
3818	0.440		0.368	0.566		—54	—58	
3761	0.459		0.351	0.579		—70	—62	
3704	0.473		0.361	0.602		—71	—46	
[illegible]	0.487		0.343	0.646		—93	— 8	

On the basis of these relationships, the purely statistical relation (in Section 3) between the spectral gradients and visual extinction may now also be treated. When the fog component $g_D = \alpha k_D \lambda$ is introduced into the gradients $g = g_R + g_D$, and k_D is replaced by $k_v - (k_R + k_{O_3})$, by definition, then there is obtained for wavelength $\lambda = 550$ m with the given numerical values

$$g = 0.186 + 0.825\ k_v.$$

This relation is shown in Figure 1 near the regression line. Because of its systematic foundation, it is more advantageous than the statistical result for the determination of the gradient from the visual extinction.

8. The Wavelength Exponent of the Fog Extinction from Observations and Other Sources

If the interpolation formula for the fog extinction used at the Jena observations were to attain general validity with about the same wavelength exponents, then the consideration of the extinction at the spectral photometric investigations would need to be considerably simplified and would not require a new empirical determination at each observation location or even for each night of observation. It is therefore of interest to check whether the spectral photometric extinction observations available from other locations could also be represented by the equation $k_D = 1.086\ \beta/\lambda^{\alpha}$. This question has already been discussed from the meteorological standpoint, since the use of the coefficient β as a measure of turbidity, which was proposed by A. Ångstrom [3], is derived from the assumption that the wavelength α of the fog extinction is a universal constant. Ångstrom found this assumption confirmed, with a value $\alpha = 1.3$, from the spectral bolometric extinction determinations carried out within the framework of the solar constants determinations of the Smithsonian Institution in Washington and on four mountain stations (Bassour 1,160 m; Hump Mountain 1,500 m; Mount Wilson 1,780 m; and Calama 2,250 m); he believed that he could conclude from this on a uniform diameter of the fog particles of the order of magnitude of 1μ. In contrast to this, however, F. Linke [24] found from the same observation material a systematic increase of the exponent α with the altitude of the observation locations, and he saw in this result a confirmation of the suspected decrease of the average particle size with altitude. The reason for this contradiction is to be sought in the different procedures for deriving α: Ångstrom uses for the molecular extinction the theoretical amount according to Rayleigh and limits himself in the calculation of the exponent α to the two wavelengths 450 mμ and 900 mμ. The ozone absorption therefore does not play any part in this. Linke, on the other hand, deducts the empirical extinction coefficient extrapolated by Fowle from the disappearing water vapor content and derives the constants α and β by a graphical equalization for the whole spectral range. Linke also considers it necessary to reduce the observed extinction coefficients to normal pressure by multiplication with $760/b$, in order to obtain in the coefficient β a measure of the specific, i.e., the turbidity on the basis of the same true mass of air; while Ångstrom determines from the unreduced extinction coefficients the actual mass of turbidity present at the observing station. The values of β therefore differ by the factor $760/b$ for Linke and Ångstrom, while according to Linke, the value of α is not altered by this difference. Actually, however, the ozone absorption is also affected by the reduction of the observed extinction coefficients. Thus, for example, /14 it is increased at mountain stations by the factor $760/b$, while for the derivation of the fog extinction it is only reduced by the normal value (i.e., with the Mt. Wilson result it increased by the factor $760/b$). Even though this error is not very great, it can make itself felt as a systematic response to the altitude. In any case, it is fundamentally better to dispense with the reduction of the observed extinction coefficients to normal pressure, since it is only significant for the molecular component; while it is wrong for the ozone absorption and has only a purely formal significance for the fog extinction.

The recent discussion reported in the following sections about the extinction determinations available in the literature, therefore proceeds from the unreduced results of observation and treats the various extinction components according to their own mathematical interrelationship. The derivation of the fog extinction was followed in detail in the same way as for the observations at Jena. The molecular extinction (for the Rayleigh amount) for the corresponding air pressure and the ozone absorption, according to the absorption coefficients determined by laboratory investigations, was subtracted from the measured total extinction. Where the air pressure was not known directly at the time of the extinction observation, the Rayleigh extinction was computed with the average air pressure corresponding to the local altitude level. The systematic variation of the equivalent layer thickness with the geographic latitude and the time of year was taken into consideration for the value of the ozone absorption.

In order to compensate for an arbitrary choice which is difficult to avoid during graphic equalization, the constants α and β were derived by the equalizing computation of the relation

$$\log k_D(\lambda) = -\alpha \log \lambda + \log \beta + 0.036$$

in the interval 400 mμ < λ < 700 mμ (insofar as it is covered by measurements). The average errors that are obtained thereby are, of course, only a criterion for the inner precision of the representation and not for the absolute uncertainty, which can be particularly greater for the fog magnitudes at the mountain stations. Whenever possible, only the directly observed was used as the basis for workup, i.e., not recalculated later to other wavelengths or used graphically interpolated extinction coefficients, since the wavelengths exponent α could easily be influenced by a smoothing out. Furthermore, the underlying principles and procedures were subjected as much as possible to a control. This, for example, proved to be most informative for the transmission coefficients of Abney [2] which were carried out differently [for example in [33]] than for a confirmation of the Rayleigh λ^{-4} law for total extinction. Actually, for the Abney measurements, the reflected, nonrefracted solar light from the first prism surface served as comparative brightness for the individual wavelengths, so that fundamentally a neutral component of the extinction could not be detected. These observations, therefore, could not contribute anything toward the investigation of fog extinction.

The following paragraphs first give some explanations about the spectral photometric extinction investigations at the various locations: the results for the constants α, β, and *K* of the fog extinction are then summarized in a review in the next section.

a) Goettingen

Two observational series for the determination of the extinction were carried out within the limits of the Goettingen spectral photometric investigations, both according to the procedure used at Jena for the measurement of star pairs. The first series was obtained during 1930-31 with nonexpanded lattice exposures and extends only to the short wave portion of the spectrum ($\lambda < 500$ mμ). The number of observations is rather great, but the weight of the individual measurement is low, because the zenith distance was restricted during the exposures to a maximum of 50% due to the danger present for unexpanded exposures of a systematic falsification by the atmospheric disturbance. The path length difference for the two stars, therefore, amounted to only 0.3-0.5. The results of this observational series are reported separately in groups according to visibility [38] and are represented by an exponential equation for the total extinction. The same unrefined material was then used for the derivation of the fog extinction. The groups with the best visibility were eliminated from this, since they are represented practically by Rayleigh scattering itself (the ozone absorption generally lies outside the observed spectral range). There thus remain for treatment a group (a) of average visibility of the star pair β Cass----α Pers and one each of a group of average (b) and poorer (c) visibility of the star pair β UMaj--η UMaj. The second series of observations [20] was set up in 1934-35 for the exposures in connection with the stellar radiation on a terrestrial source of light of known intensity distribution and was supposed to serve for the control of the extinction occurring here with full magnitude. The stellar spectra were expanded and exposed on panchromatic film, but always without lattice and not always in symmetrical arrangement of the star pair serving for the extinction determination. The reduction was made with optical /15 density curves, which were obtained from the lattice exposures of the artificial star. The treatment was particularly difficult in the range of about 500 mμ, because the low sensitivity of the photographic layer coincides here with a fast change in gradation and an increased difference in optical density between star spectra and scale exposures. The individual results show an erratic behavior in this region due to the lower precision of measurement, which must be rendered harmless by averaging or smoothing. Inasmuch as there is unavoidably some latitude in this process of treatment by arbitrary choice, several possibile solutions were discussed which would evaluate the influence on the parameter of fog extinction. The method reported in [20], based on twelve "systematically improved" night values derived by F. Beileke, was designated Solution A. Another total method (B) was formed from the original data of 13 nights without assigning any weight. The same material was further separated into two groups according to visibility, in which the observations of 6 nights with greater visibility (Solution C) were combined with those from 7 nights with lower visibility (Solution D) with rounded off weights regarding the path length difference used. The monochromatic extinction coefficients for these four combinations are assembled in Table 7. For the wavelength exponents of the fog extinction there was obtained a difference between Solution A on the one hand, and the other solutions on the other hand, which markedly exceeded the formally calculated average error. This must be ascribed to the influence of the graphic rounding off for solution A and on the elimination of an observation.

TABLE 7. GOETTINGEN EXTINCTION COEFFICIENTS.

λ	1/λ	A	B	C	D
631 mμ	1.584	0.306	0.283	0.188	0.363
614	1.630	0.323	0.305	0.209	0.384
597	1.676	0.340	0.331	0.229	0.407
581	1.722	0.349	0.320	0.224	0.414
566	1.768	0.363	0.338	0.229	0.434
551	1.814	0.363	0.337	0.232	0.420
538	1.859	0.381	0.356	0.247	0.449
525	1.904	0.383	0.373	0.257	0.461
513	1.949	0.399	0.391	0.266	0.483
502	[illegible]	[illegible]	0.432	0.293	0.538
[illegible]	2.0[illegible]	[illegible]	0.450	0.315	0.5[illegible]5
[illegible]	2.082	[illegible]	[illegible]	[illegible]	0.530
[illegible]	[illegible]	[illegible]	[illegible]	0.320	0.540
[illegible]	[illegible]	[illegible]	[illegible]	0.31[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0.327	0.554
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.735
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

In addition to these two series of observations at Goettingen, there are also the older extinction observations of H. Rosenberg [33]. These, however, do not present any independent determination of the amount of extinction, but only graphically rounded off values of relative reduction factors of the Potsdam visual extinction table. Therefore, results for the parameter of the fog extinction ($\alpha = 2.53 \pm 0.25$; $\beta = 0.044 \pm 0.007$), which greatly deviates from the more recent Goettingen series, cannot be given any importance.

b) Kiel

Some individual stars were followed spectrophotometrically in the observations initiated by H. Jensen [17]. The results of 8 nights with 19 observed stars are given directly as average value of k_λ, so that a separation according to differing visibility is not possible.

c) Babelsberg

The derivation of the transmission coefficients was carried out by W. Becker [5] on six nights with part good and part average visibility by observations of a star pair which was exposed alternately in the east and west. The /16
extinction coefficients in the west were always $0^{\mathrm{m}}.11$ greater than in the east. The average was used for the derivation of the fog extinction, since the difference could not be clearly explained.

d) Potsdam

The numerous reports about the spectral transmission of the terrestrial atmosphere which may be found in the publications about the extensive spectrophotometric and bolometric work carried out at Potsdam are not independent of each other, but go back exclusively to the same surprisingly few observations. Thus, all extinction corrections which are given about the temperatures of the stars in the investigations of Wilsing and Schneider (Publ. Nos. 56 and 74) rest on the visual spectrophotometric measurements of the sun which G. Mueller [29] carried out in six days during 1882 (only in the afternoon), and whose results for the transmission coefficients were later reported parenthetically in another connection (Publ. Vol. 8, p. 7). Only the original observations were used for the discussion of the fog extinction.

A similar series of measurements were carried out by G. Mueller and E. Kron [32] at the end of the Teneriff Expedition (Publ. 64) in the fall of 1909 on three sunny days and the next moonlit evening. The morning and afternoon observations of the individual days treated separately show considerable wavelength dependence differences, so that the fear expressed by J. Wilsing [41] about a systematic falsification of the transmission coefficients by transient variation of visibility prove correct to a high degree for these measurements. This short series of measurement should therefore not be given any great weight. A report about the results of a new treatment of the Teneriff observations can be foregone here, since these measurements do not carry any weight worth mentioning because of their low number and the narrow spectral range that they encompass compared to the wealth of material from the mountain stations of the Smithsonian Institution.

An extension of the extinction determination on the short wave portion of the spectrum was undertaken by J. Wilsing [40] through photographic exposures of the solar spectrum on three days in June 1911. The evaluation, however, was only followed relatively with an assumed visual transmission coefficient ($k_{590} = 0.805$), so that these measurements cannot yield an independent contribution to the fog extinction and can only serve for the derivation of a gradient (compare Table 4).

A larger number of extinction determinations is contained in the spectrobolometric investigations of J. Wilsing [41] for the determination of the solar temperature. The results are subjected to a very detailed discussion, in which the individual steps are not always entirely clear in their meaning. The directly observed values of the transmission coefficients (Solution A) receive a systematic improvement (Solution B) because of the periodic variation of visibility during the course of a day. These improved values serve for the derivation of the energy distribution in the solar spectrum, from which the "true" transmission coefficients (Solution C) were then derived, while a few graphic and computational rounding off procedures gave the "normal curve" of the extinction for Potsdam. An example as to how far the various reductions affect the determination of the fog extinction, the material of the 1914 observation was used for the derivation of the parameters α and β from all four solutions, with the following result:

Solution A	$\alpha = 0.86 \pm 0.12$	$\beta = 0.142 \pm 0.010$	$K = 0^m257$
Solution B	1.13 ± 0.09	0.108 ± 0.004	0.232
Solution C	0.88 ± 0.08	0.159 ± 0.008	0.292
Normal curve	1.15 ± 0.15	0.106 ± 0.009	0.230

One can see from these numbers how strongly the results from the same observational material can be influenced by subsequent treatment. The fog extinction designated B is to be taken as the decisive solution, since it contains all confirmable systematic improvements, but has not yet been subjected to any rounding off.

While the transmission coefficients discussed above were obtained only as a subsidiary result during the determination of the spectral energy distribution of the sun, J. Wilsing [42] undertook in 1917 and 1918 further extensive bolometric measurements in the solar spectrum for the purpose of investigating atmospheric transmission. In order to free himself from the feared main source of error, the periodic variation of visibility during the course of a day, Wilsing did not determine in this work the transmission coefficients from the variation of the observed intensity with the path length (zenith distance), but rather derived these for the individual zenith distances from the ratio of the intensities measured at the various wavelengths and the postulated energy distribution in the solar spectrum. The results thus contain the extinction values used in the determination of the solar temperature and their dependence on wavelengths, so that the transmission coefficients are not independent of one another. Furthermore, the spectral transmission of the whole arrangement of measurements, which also become a part of the extinction results, could only /17 be determined independently for the longwaved portion of the spectrum in the laboratory. For the shorter wavelengths, it was derived from the previously photographically determined (Publ. 66) energy curve ($\lambda < 660$ mμ) of the Sun. The extinction values given here, which rest on a few observations, also enter into the new extinction determination. It must be further considered that the spectral exposures of the solar spectrum with its abundance of lines, which the spectrograms obtained with greater dispersion, should be appreciably better than the bolometric measurements, so that the relative energy distribution cannot be set equal to each other in the two cases without further consideration.

On this basis it may be expected that the transmission of the order of measurement will be found too low by a value which is approximately equal to the depression of the solar continuous spectrum by the absorption lines which were not dissociated by the bolometric measurements. The atmospheric transmission will then come out too great by the same factor. Actually, there are systematic differences (Publ. 80, p. 40) between the transmission coefficients determined from the absolute intensities and the experimentally calculated values from the various wavelengths, which must be free from the considered sources of error, which deceptively coincide well with the depression of the solar continuous spectrum (the determination of which was already described in the same manner on p. 25), as shown in the following arrangement:

Wavelength	486	527	556	665 mμ
Difference of k_λ	$0^m.065$	$0^m.042$	$0^m.040$	$0^m.015$
Line absorption	0.064	0.057	0.058	0.017

When the differences are applied as systematic correction, then the wavelength exponent α of the fog extinction, which gives an uncorrected, average Wilsing value of 1.7, is reduced to about 1.2, that is, almost to the value from the previous series of observations, which must be the case according to the reasoning used. The conjecture already voiced by F. Linke [24] about the Wilsing transmission coefficients of a systematic falsification is thus completely confirmed.

e) Upsala

In 1912 at the Physical Institute of the University of Upsala, F. Lindholm [23] carried out bolometric recordings of the solar spectrum at various zenith distances. The transmission coefficients for 32 wavelengths from 462 mμ to 3.56 μ derived from these were published in detail, so that they could be grouped according to visibility for the investigation of the fog extinction. The first group contains the afternoon measurements of 22 April, 7 May, and 11 June, the second those of 21 April, the morning of 22 April and 2 July; the third those of 6, 7 and 8 July as a severe haze set in because of the volcanic ash from the Katmai eruption. The observations have already been employed by A. Ångstrom [3] and F. Linke [24] for the determination of fog extinction. The wavelength exponent (α = 1.15, or 0.91, respectively) found by Linke deviates considerably from the Ångstrom results ($\alpha = 0.5$ to 0.7) and the values found here for the different groups (0.12, 0.51, 0.67).

f) <u>Washington</u>

Of the numerous spectrobolometric extinction determinations in Washington, which were published in the Annals of the Astrophysical Observatory of the Smithsonian Institution [1], the individual values given in Vol. II, Table 17 for 20 days of the years 1903-1907 were chosen for workup, since they obviously represent the original results without interpolation to in directly measured wavelengths. Three groups were separated according to the average values of the transmission coefficients. Besides these, the average of the whole was also used. The group averages $k_D(\lambda)$ of the fog extinction are represented in Figure 4 on a log-log scale. The slight deviations of the unrefined values from the equalizing straight lines point to the fact that the exponential equation applies very well to the observations of the whole spectral range considered. The values $k_D' = k_{observed} - k_R$, that is the extinction values reduced only by the Rayleigh extinction, are shown in Figure 4 as open circles. Their deviation from the filled-in points (k_D) shows the value of the ozone absorption. The good fit of the points on a linear course also of the range affected by the ozone influence, shows that the cited absorption values are correct.

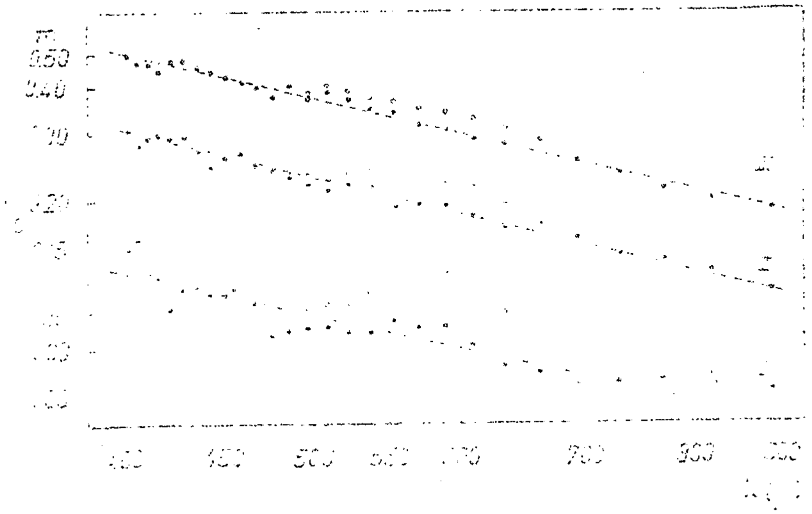

Figure 4. Fog Extinction According to Observation in Washington. o, $k_D = k_{obs.} - (k_{Rayleigh} + k_{ozone})$; 0, $k_D = k_{obs.} - k_{Rayleigh}$. I, Five days with good visibility; II, Ten days with average visibility; III, Five days with poor visibility.

g) Mountain Stations of the Smithsonian Institution

The Smithsonian Institution set up a series of mountain observatories in climatically favorable regions, i.e., at the dryest and most dust-free locations, for the determination of solar constants. The bolometric recordings of the solar spectrum required for the reduction of the radiation measurements represent extraordinarily abundant material of extinction observations, which was made available by the detailed publication in the Smithsonian Annals [1]. The hitherto existing treatments of the transmission coefficients of these /18 mountain stations dealt wholly with the aim of confirming the λ^{-4} law of molecular extinction and of determining the Avogadro number from them (compare for example [12]). Section 4 already pointed out the difficulties which arise by the extrapolation to an atmosphere free of water vapor, or dust, and the assumption of a neutral remaining term. For the procedure carried out here, by derivation of the fog extinction from the observations with the subtraction of the calculated molecular component and the ozone absorption, the inherent difficulty is due to the slight remaining value being very sensitive to small variations in the applied values of the two other components. This makes understandable the considerable differences which are shown in the wavelength exponents of the fog extinction compared to other determinations, for example, those of F. Linke, from the same material of observation. For the treatment of the observations from the various stations, the following may be remarked:

From the Bassour (Algeria) station, the average value reported in the Annals, Vol. III, p. 136 of 9 days from August 1911 to June 1912, as well as the result of 2 days in August 1912 with anomalous haze due to volcanic dust, was used. For Hump Mountain (North Carolina), the average transmission coefficients of nine chosen days of the years 1917-18 were made the basis for investigation of fog extinction.

Of the observations at Harqua Hala, a choice was made of the completely published material of 1920-25 (Annals, Vol. V, p. 177-182), that is, according to the spectroscopically determined total atmospheric content of precipitable water (p.w.), on the one hand, the days with the lightest water content (p.w. $<$ $<$ 1.5 mm, average 1.16 mm from 29 days) and on the other hand, those with particularly high water content (p.w. $>$ 10.0 mm, average 12.95 mm from 22 days) were taken out and the observed transmission coefficients determined. Furthermore, the difference between these two group averages was also represented by the exponential equation $k_D = \beta/\lambda^{\alpha}$, since this served as a possibility of checking the correctness of the whole procedure. If the absolute amounts of extinction should give the same wavelength exponents for slight and strong haze, then the amount of the difference should also lead to the same value of α. Now, since there is no assumption in the difference about molecular extinction and ozone absorption, while the result from the absolute amounts are dependent to a high degree on the assumed values for these components, then the agreement of the results would represent a rather sensitive criterion. In any case, if different values of α were to be obtained from the absolute values of extinction for light and heavy water content, unambiguous conclusions could not be drawn, since in this case we must assume a different character of the fog for light and heavy moisture, for example, a marked dust content of the dry atmosphere.

The measurements from two other stations were used for this possible check /19
method, for which individual data were published. From the observation on Table Mountain in California (Annals, Vol. V, p. 183-190), there were used 39 days with a water content under 1.4 mm (average p.w. = 1.07 mm) and 31 days with a water content over 12.0 mm (average p.w. - 16.21 mm). From the material of Montezuma in Chile (Annals, Vol. R, p. 169-176), there served for this purpose 33 days with p.w. < 1.0 mm (average 0.78 mm) and 45 days with p.w. > 10.0 mm (average value 12.43 mm).

Of the results of the Mt. Wilson observatory, there were used for the derivation of extinction the published average values of 9 selected days of 1909-12 (Annals, Vol. III, p. 138) and the observations on two days disturbed by volcanic dust of August 1912. For the Calama (Chile) station there were used directly the published average values (Annals, Vol. IV, p. 199) of 12 normal days of the years 1918-19 as well as two days each of particularly good and particularly poor visibility.

9. Summary and Discussion of the Results

The results for the fog extinction from the observation at locations of low altitude are reproduced in Table 8. The various columns contain, in addition to the value of the location and the time of observation, the number N of the days or nights, which have contributed measurements for the individual groups. Then follow the constants α, β, and K of the fog extinction as well as a short indication of the method of observation. It is noteworthy that until now there has apparently been no spectrophotometric extinction investigation at any one location which had been carried out by day or by night.

The fact that the extinction observations at Jena for all degrees of haze lead to the same power ($\alpha = 1.5$) of the reciprocal wavelength, was already emphasized in Section 7. The measurements at Kiel and Babelsberg agree with this concept, whereby the much greater visibility, particularly at Bebelsberg, is noticeable. Against this, the fog extinction at Goettingen follows an appreciably smaller wavelength exponent. Although the individual values are somewhat scattered with varying visibility, they do not show any clear trend with the haze and can be summarized with an average value of roughly 0.9, with consideration of their uncertainty.

It seems at first surprising that the wavelength dependence of the extinction should show such variable behavior at two locations which are only 130 km apart, are at the same altitude (160 m), and are in somewhat similar landscape. /20
The accuracy of the results are, however, not to be doubted, since the studies at both locations were carried out by the same procedure, by the same observer, and even by the same photometric system. Therefore, in spite of the ever present interchange of air masses, it appears that local peculiarities express themselves in the fog extinction, which at Jena could very well be looked for in the greater proportion of haze of industrial origin.

The extinction studies at Potsdam lead to an average exponent of about 1.25, with the exception of the doubtful visual series of the year 1909. Due to the small number of days of observation it cannot be determined whether the increase in the visual fog extinction for the more recent observations compared to the older series is due to an incidental choice or can be ascribed to an actual worsening of the average visibility.

The results at Washington, at an equally great range of turbidity as for the Jena measurements, show a completely constant wavelength exponent, which amounts to about 1.2. On the other hand, the α-values at Upsala show a variation with the turbidity, namely, in a reverse order than that expected, since low turbidity must be the result of smaller particles and therefore should show a higher exponent. Exactly the same value (α = 0.68) as in the third group from Upsala, which refers to the three days in July 1912 disturbed by volcanic dust, is found in Table 9 under the results of the mountain stations for the same period (Bassour α = 0.68; Mt. Wilson α = 0.66). A notable indication of the uniformity of the anomalous turbidity spread over the whole terrestrial atmosphere by the Atmai eruption.

TABLE 8. PARAMETERS OF THE DUST EXTINCTION AT DIFFERENT LOCATIONS.

Ort	Zeit		N	α	β	K	Methode
Jena	1941—42	I	6	1.53 ± 0.06	0.090 ± 0.004	0.244	Star phot.
		II	6	1.56 ± 0.05	0.132 ± 0.002	0.304	,, ,,
		III	6	1.46 ± 0.05	0.239 ± 0.001	0.622	,, ,,
Göttingen . .	1930—31	a	11	0.59 ± 0.31	0.141 ± 0.035	0.218	,, ,,
		b	14	0.75 ± 0.18	0.162 ± 0.023	0.270	,, ,,
		c	5	1.07 ± 0.16	0.250 ± 0.032	0.515	,, ,,
	1934—35	A	12	0.68 ± 0.06	0.150 ± 0.006	0.245	,, ,,
		B	13	0.90 ± 0.11	0.122 ± 0.009	0.227	,, ,,
		C	6	1.02 ± 0.20	0.058 ± 0.006	0.116	,, ,,
		D	7	0.84 ± 0.07	0.178 ± 0.009	0.319	,, ,,
Kiel	1931—32	—	8	1.58 ± 0.12	0.067 ± 0.006	0.167	,, ,,
Babelsberg . .	1934	—	6	1.52 ± 0.24	0.034 ± 0.006	0.092	,, ,,
Potsdam . . .	1882	—	—	1.28 ± 0.25	0.045 ± 0.007	0.103	Sun vis.
	1909	—	3	0.45 ± 0.33	0.110 ± 0.023	0.165	,, ,,
	1913	—	15	1.37 ± 0.12	0.115 ± 0.011	0.284	,, bol.
	1914	—	13	1.13 ± 0.09	0.092 ± 0.004	0.106	,, ,,
[illegible]	1912	I	3	[illegible]	[illegible]	[illegible]	
		II	[illegible]	[illegible]	[illegible]	[illegible]	
		III	5	[illegible]	[illegible]	[illegible]	,,
[illegible]	[illegible]	M	20	[illegible]	[illegible]		
		I	5	[illegible]	[illegible]	[illegible]	,,
		II	10	[illegible]	[illegible]	[illegible]	
		III	5	[illegible]	[illegible]	[illegible]	,,

The wavelength exponents of the fog extinction from the mountain stations summarized in Table 9 do not confirm either the constant value α = 1.3 found by Ångstrom or the increase with the altitude of the place of observation expected by Linke. Most of the exponents, particularly the results from stations above 2,000 m, group themselves around the value α = 0.9. Clear deviations from these and even larger values occur only at the lower situated stations (Bassour 1,160 m, α = 1.73; Hump Mountain 1,500 m, α = 1.24; Mt. Wilson 1,780 m, α = 1.39).

TABLE 9. RESULTS OF THE MOUNTAIN STATIONS

Name	Altitude m	α	β	K	Remarks
Bassour	1160	1.73 ± 0.24	0.020 ± 0.003	0.061	Average of 9 days
		0.68 ± 0.05	0.154 ± 0.097	0.251	2 disturbed days 1912
Hump Mountain .	1500	1.24 ± 0.13	0.025 ± 0.002	0.058	Average of 8 days
Harqua Hala . .	1721	0.92 ± 0.19	0.012 ± 0.002	0.043	p. w. = 1.16 mm
		1.09 ± 0.06	0.028 ± 0.001	0.058	p. w. = 12.95 mm
		1.20 ± 0.11	0.015 ± 0.004	0.054	Difference
Mt. Wilson. . . .	1780	1.39 ± 0.27	0.014 ± 0.002	0.034	14 Chosen days
		0.66 ± 0.10	0.135 ± 0.005	0.217	2 disturbed days 1912
Calama	2250	0.89 ± 0.10	0.027 ± 0.002	0.050	Average of 12 days
		0.48 ± 0.28	0.016 ± 0.003	0.028	good visibility
		1.33 ± 0.07	0.049 ± 0.002	0.118	poor visibility
Table Mountain .	2286	0.93 ± 0.21	0.015 ± 0.002	0.030	p. w. = 1.07 mm
		1.48 ± 0.12	0.023 ± 0.002	0.060	p. w. = 16.21 mm
		1.94 ± 0.12	0.008 ± 0.001	0.030	Difference
Montezuma . . .	2711	0.93 ± 0.15	0.012 ± 0.001	0.022	p. w. = 0.78 mm
		0.83 ± 0.12	0.032 ± 0.002	0.058	p. w. = 12.43 mm
		0.84 ± 0.20	0.020 ± 0.003	0.036	Difference

The analysis of the differences between group averages of the same station speaks for the reduction procedure used, insofar as it is possible to draw a conclusion after the discussion in the previous paragraph. For the results from Harqua Hala and Montezuma, the wavelength exponents from the absolute amounts of the extinction for the two groups with extreme water content agree with one another completely within the limits of their average error, and with the result of the difference formation. The measurements of the Table Mountain station lead to a smaller value of α at better visibility than at greater turbidity. If this difference were ascribed to an incorrect estimate of the other extinction components, a considerably smaller value must be applied for the molecular extinction in order to achieve an agreement of the α-values. Therefore, these data also speak *against* an increase of the Rayleigh extinction amount by the anisotropy factor of Cabannes. Furthermore, one must interpret the differences in the wavelength exponents in such a way that for this station an extinction that is less dependent on wavelength by dry haze is superimposed over a water-fog extinction with greater wavelength exponent. A similar result is found for the Calama observations, where the days with particularly good visibility lead to a smaller wavelength exponent ($\alpha = 1.33$). It appears therefore that for mountain stations there are also local differences in the composition of the fog which affect the wavelength exponents. /21

One must conclude from all the observations that even though the exponential equation has been found to be a useful interpolation formula for the fog extinction at particular locations, it cannot be generalized with a constant exponent as is assumed by the use of the coefficient β as a measure of turbidity.

10. The Approximate Computation of Monochromatic Extinction Coefficients

Based on the above experiences it does not appear to be fundamentally possible to transfer the monochromatic extinction coefficients observed at one location to other conditions. Still, the differences in the extinction amounts which are obtained by the local variation of the wavelength exponents α are so slight in comparison with the periodic shifts in visibility, that the possible computation, first shown in Section 7 for the conditions at Jena, of monochromatic extinction coefficients from the observed amount of extinction and the parameter representation of the fog extinction is generally applicable. To facilitate the computation there are given in Table 10 the values $k_D(\lambda)$ for a few wavelength exponents, covering the whole range of variation of α, under the assumption of a visual fog extinction $K_D = 0^m200$. The values in the table thus give the total amount of the extinction with the corresponding wavelengths multiplied by the proper factor along with the Rayleigh extinction according to Table 5 and the ozone absorption from Figure 2.

It is sufficient to have an approximate knowledge of the wavelength exponent α in order to obtain the monochromatic extinction coefficients from the observed magnitude of the extinction $k(\lambda)$, even at the limits of the considered spectral range, with about the same accuracy as for a particular spectrophotometric extinction determination. For this purpose, as long as no other experience is available, 0.9 can be used as the value for the wavelength exponent for mountain stations and locations free of smoke and dust, and the value 1.5 for locations with pronounced turbidity, according to the results reported above.

TABLE 10. FOG EXTINCTION FOR DIFFERENT WAVELENGTH EXPONENTS.

λ	0.6	0.9	1.2	1.5
400 mμ	$0\overset{m}{.}242$	$0\overset{m}{.}266$	$0\overset{m}{.}293$	$0\overset{m}{.}324$
420	0.235	0.255	0.276	0.300
440	0.228	0.244	0.261	0.280
460	0.223	0.235	0.248	0.261
480	0.217	0.225	0.236	0.245
500	0.212	0.218	0.224	0.231
550	0.200	0.200	0.200	0.200
600	0.190	0.185	0.180	0.176
650	0.181	0.172	0.164	0.156
700	0.173	0.161	0.149	0.139

REFERENCES

1. Abbot, C. G., and F. E. Fowle, *Ann. Astrophys. Obs. Smithsonian Inst.*, Vol. 2, 1908; Vol. 3, 1913; Vol. 4, 1922; Vol. 5, 1932.
2. Abney, W., "Transmission of Sunlight Through the Earth's Atmosphere," *Phil. Trans. Roy. Soc.*, London, Vol. 178, p. 251, 1887.
3. Ångstrom, A., "On the Atmospheric Transmission of Sun Radiation and on Dust in the Air," *Geogr. Ann.*, Vol. 11, p. 156, 1929.
4. Barbier, D. and D. Chalonge, "Investigations of Atmospheric Ozone," *J. Phys. Radium*, Vol. VIII, No. 10, p. 113, 1939.
5. Becker, W., "Photoelectric Color Indices of 738 Stars. II. Results of Observation," *Veroff. Univ. Sternw.*, Berlin-Babelsberg, Vol. 10, p. 6, 1935.
6. Cabannes, J., "Diffusion of Light Through Molecules of Transparent Gas," *Ann. Phys.*, Paris, Vol. 15, p. 5, 1921.
7. Cabannes, J., and J. Dufay, "Transparency of the Atmosphere in the Visible Spectrum. Molecular Diffusion. Absorption by Ozone," *J. Phys. Radium*, Vol. VI, No. 7, p. 257, 1926.
8. Colange, G., "Absorption by Ozone in the Visible Spectrum," *J. Phys. Radium*, Vol. VI, No. 8, p. 254, 1927.
9. Fowle, F. E., "The Non-Selective Transmissibility of Radiation Through Dry and Moist Air," *Astrophys. J.*, Vol. 38, p. 392, 1913.
10. Gerasimovic, B. P., "Spectrophotometric Temperatures of Early Stars," *Harvard Coll. Obs. Circ.*, No. 339, 1929. /22
11. Goetz, F. W. P., "The Atmospheric Ozone," *Ergebn. kosm. Phys.*, Vol. 1, p. 180, 1931.
12. Goetz, F. W. P., "Turbidity and Anomalous Extinction," *Helv. Phys. Acta*, Vol. 5, p. 336, 1932.
13. Goetz, F. W. P., "Wavelength Dependence of Fog Extinction," *Meteor. Z.*, Vol. 51, p. 472, 1934.
14. Goetz, F. W. P., "The Law of Color Change for Diffusion," *Astron. Nachr.*, Vol. 255, p. 63, 1935.
15. Goetz, F. W. P., "The Attenuation of Solar Radiation in a Clean Atmosphere," *Meteor. Z.*, Vol. 57, p. 414, 1940.
16. Greaves, W. M. H., C. Davidson and E. Martin, "The Zero Point of the Greenwich Color Temperature System," *Monthly Not. Roy. Astron. Soc.*, Vol. 94, p. 488, 1934.
17. Jensen, H., "Temperature Scales of the Fixed Stars," *Astron. Nachr.*, Vol. 248, p. 217, 1933.
18. St. John, Ch. E., et al., "Revision of Rowland's Preliminary Table of Solar Spectrum Wavelengths," Carnegie Inst., Washington, Publ. No. 396, 1928.
19. Kienle, H., H. Strassl and J. Wempe, "The Relative Energy Distribution in the Continuous Spectrum of 36 Fundamental Stars," *Z. Astrophys.*, Vol. 16, p. 201, 1938 = Publ. Univ.-Sternw., Goettingen, No. 50.
20. Kienle, H., J. Wempe and F. Beileke, "The Absolute Intensity Distribution in the Continuous Spectrum of the Average Ao-Stars," *Z. Astrophys.*, Vol. 20, p. 91, 1940 = Publ. Univ.-Sternw., Goettingen, No. 69.

21. Tien Kiu, "Atmospheric Absorption from Observations at Montezuma 1920 to 1930 by the Smithsonian Institution," *Publ. Obs.*, Lyon, Vol. 1, No. 2, p. 243, 1938.
22. Lefebvre, L., "Absorption Spectrum of Ozone at Low Temperature," *C. R. Acad. Sci.*, Paris, Vol. 200, p. 653, 1935.
23. Lindholm, F., "Extinction of Solar Radiation in the Terrestrial Atmosphere," *Nova Acta Regiae. Soc. Sci.*, Upsaliensis, Serial IV, Vol. 3, No. 6, 1912.
24. Linke, F. and H. v. dem Borne, "The Wavelength Dependence of Radiation Extinction by Haze Particles," *Gerlands Beitr. Geophys.*, Vol. 37, p. 49, 1932.
25. Linke, F., "The Extinction of Solar Radiation in Hazy Atmosphere," *Gerlands Beitr. Geophys.*, Vol. 55, p. 221, 1939.
26. Linke, F., *Handb. Geophys.*, Vol. 8, No. 1, 1942; 2, 1943.
27. Meggers, W. F. and C. G. Peters, "Measurements of the Index of Refraction of Air for Wavelengths from 2,218 Å to 9,000 Å," *Astrophys. J.*, Vol. 50, p. 53, 1919.
28. Mulders, G. F. W., "Equivalent Widths of Fraunhofer Lines in the Solar Spectrum," *Diss. Utrecht*, 1934.
29. Mueller, G., "Brightness Variations in Different Parts of the Solar Spectrum with Decreasing Height of the Sun Over the Horizon," *Astron. Nachr.*, Vol. 103, p. 241, 1882.
30. Mueller, G., "Photometric and Spectroscopic Observations on the Top of Santis," *Publ. Astrophys. Obs.*, Potsdam, Vol. 8, No. 27, 1897.
31. Mueller, G., *Die Photometrie der Gestirne* [Photometry of the Stars], Leipzig, 1897.
32. Mueller, G. and E. Kron, "Photoextinction in the Terrestrial Atmosphere and the Energy Distribution in the Solar Spectrum," *Publ. Astrophys. Obs.*, Potsdam, Vol. 22, No. 64, 1913.
33. Rosenberg, H., "Photographic Investigation of Intensity Distribution in Stellar Spectrum," *Nova Acta Abh. Kaiserl. Leopold.-Carol. Akad. der Naturforscher*, Halle, Vol. 101, No. 2, 1914.
34. Stratton, J. A. and H. G. Houghton, "A Theoretical Investigation of the Transmission of Light Through Fog," *Phys. Rev.*, Vol. 38, p. 159, 1931.
35. Tichanowsky, J. J., "Theory of Light Scattering in the Terrestrial Atmosphere," *Phys. Z.*, Vol. 29, p. 442, 1928.
36. Vassy, A., "Absorption Coefficients of Ozone in the Region of the Chappuis Bands," *C. R. Acad. Sci.*, Paris, Vol. 206, p. 1638, 1938.
37. Vassy, E., "Some Properties of Ozone and Their Geophysical Consequences," *Ann. Physic.*, Paris, Vol. 8, p. 679, 1937.
38. Wempe, J., "Photographic Spectrophotometry," *Z. Astrophys.*, Vol. 5, p. 154, 1932 = Publ. Univ.-Sternwarte, Geottingen, No. 28.
39. Williams, R. C., "Spectrophotometric Determinations of Stellar Temperatures: The Color Temperature of α-Lyrae," *Publ. Univ. of Michigan*, Vol. 7, No. 4, 1938.
40. Wilsing, J., "Brightness Distribution in Solar Spectrum After Spectrographic Measurements," *Publ. Astrophys. Obs.*, Potsdam, Vol. 22, No. 66, 1913.

41. Wilsing, J., "Brightness Distribution in Solar Spectrum After Bolometric Measurements, and the Temperature of the Solar Atmosphere," *Publ. Astrophys. Obs.*, Potsdam, Vol. 23, No. 72, 1919.

42. Wilsing, J., "Extinction of Radiation in Terrestrial Atmosphere According to Bolometric Measurements in Solar Spectrums," *Publ. Astrophys. Obs.*, Potsdam, Vol. 25, No. 80, 1924.

Translated for the National Aeronautics and Space Adminsitration under contract No. NASw-2037 by Techtran Corporation, P. O. Box 729, Glen Burnie, Maryland 21061, Translator: M. Plunguian, Ph. D.